

[54] **NON-INDUCTIVE FILM-TYPE
CYLINDRICAL RESISTOR**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 315,018, Dec. 14,
1972, abandoned.

[52] U.S. Cl. **338/62, 338/63, 338/286,**
338/292, 338/300, 338/302, 338/262, 338/332

[51] Int. Cl. **H01c 3/02**

[58] Field of Search **338/61, 62, 63, 286, 294,**
338/292, 300, 302, 308, 262, 332

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Primary Examiner—E. A. Goldberg

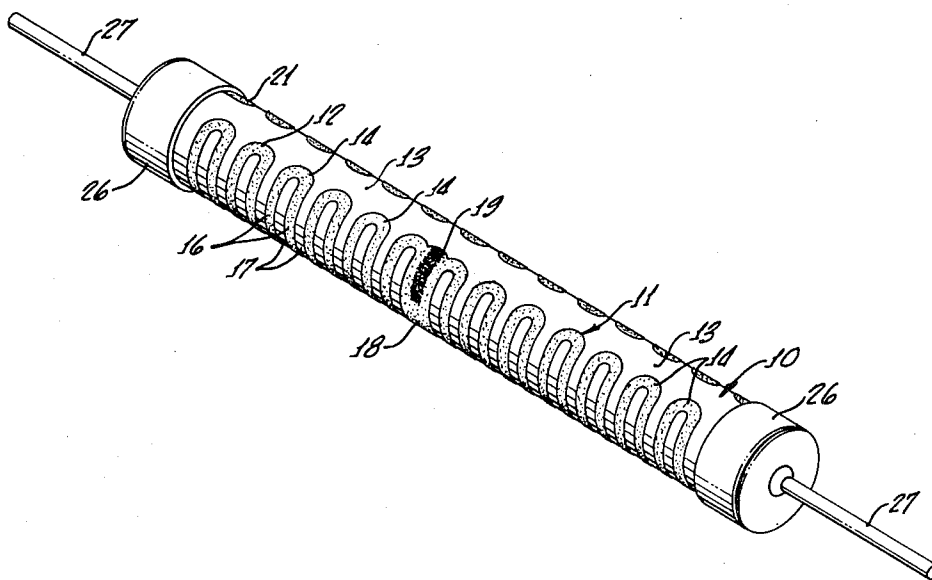
Attorney, Agent, or Firm—Richard L. Gausewitz

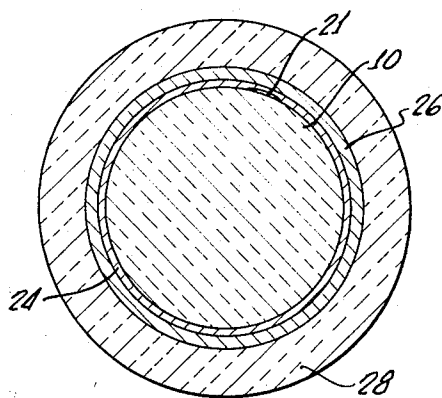
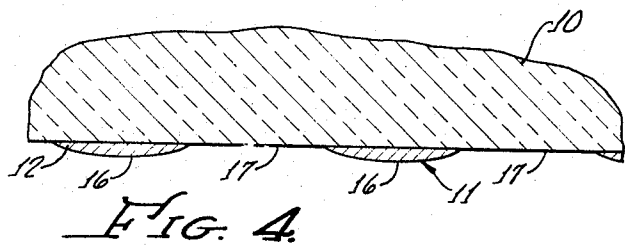
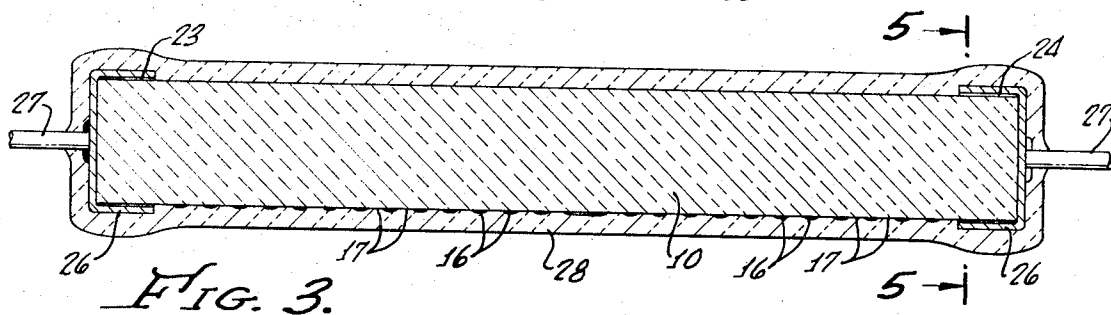
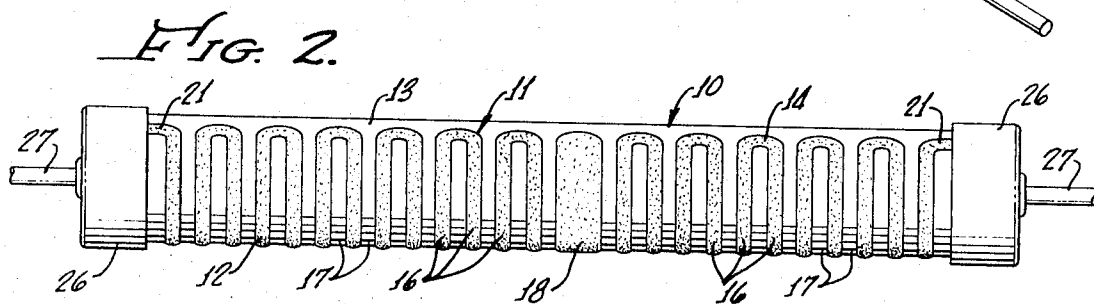
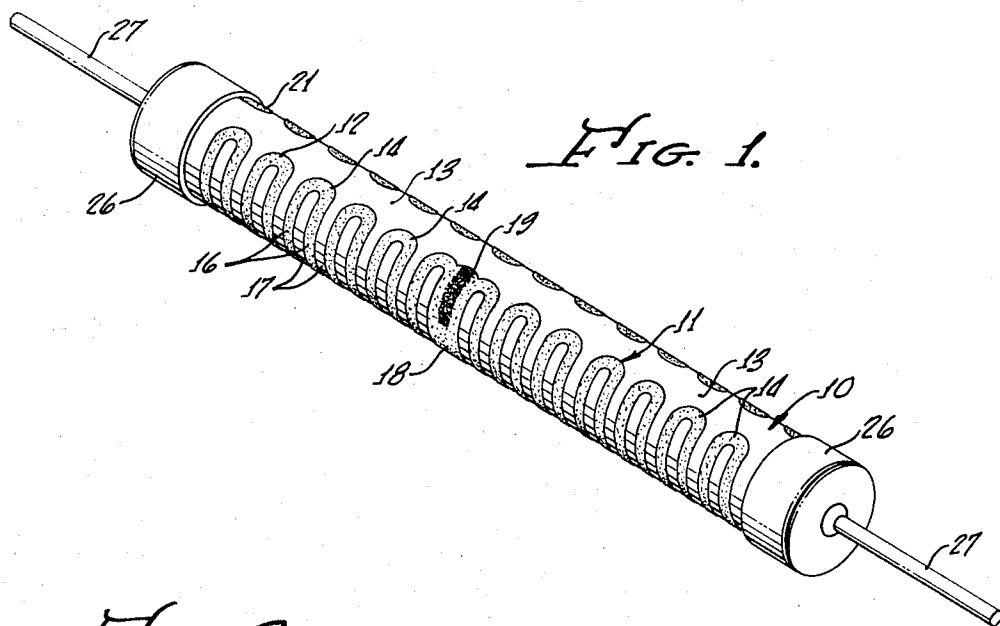
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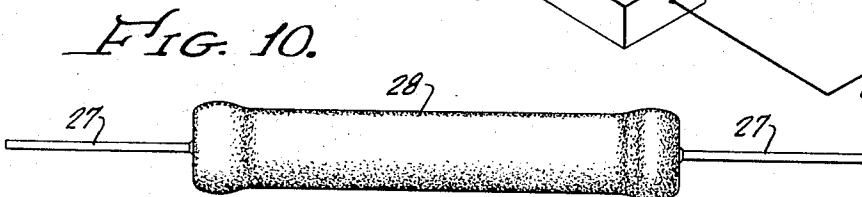
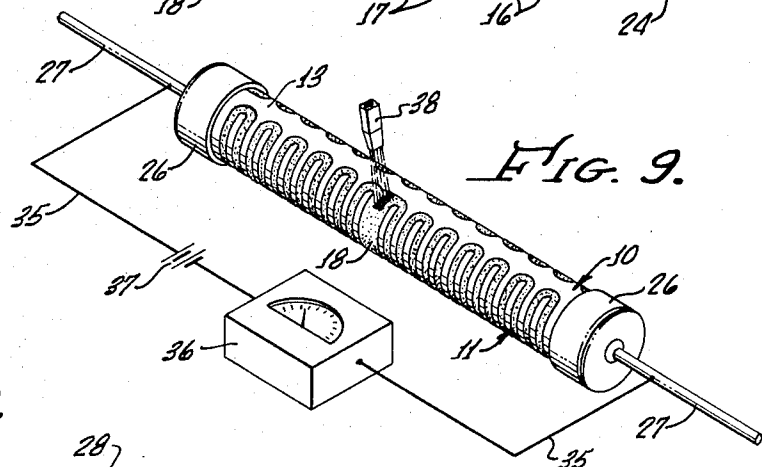
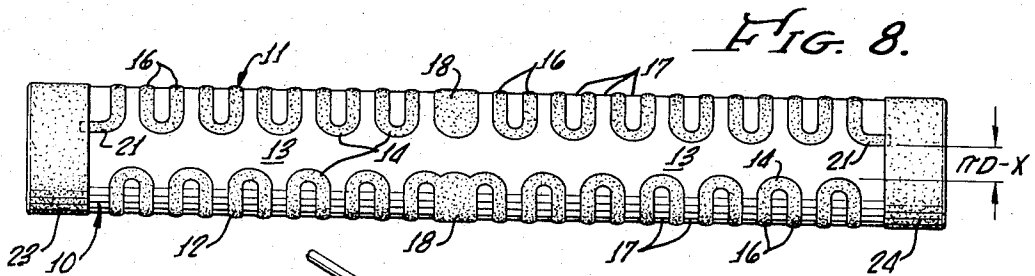
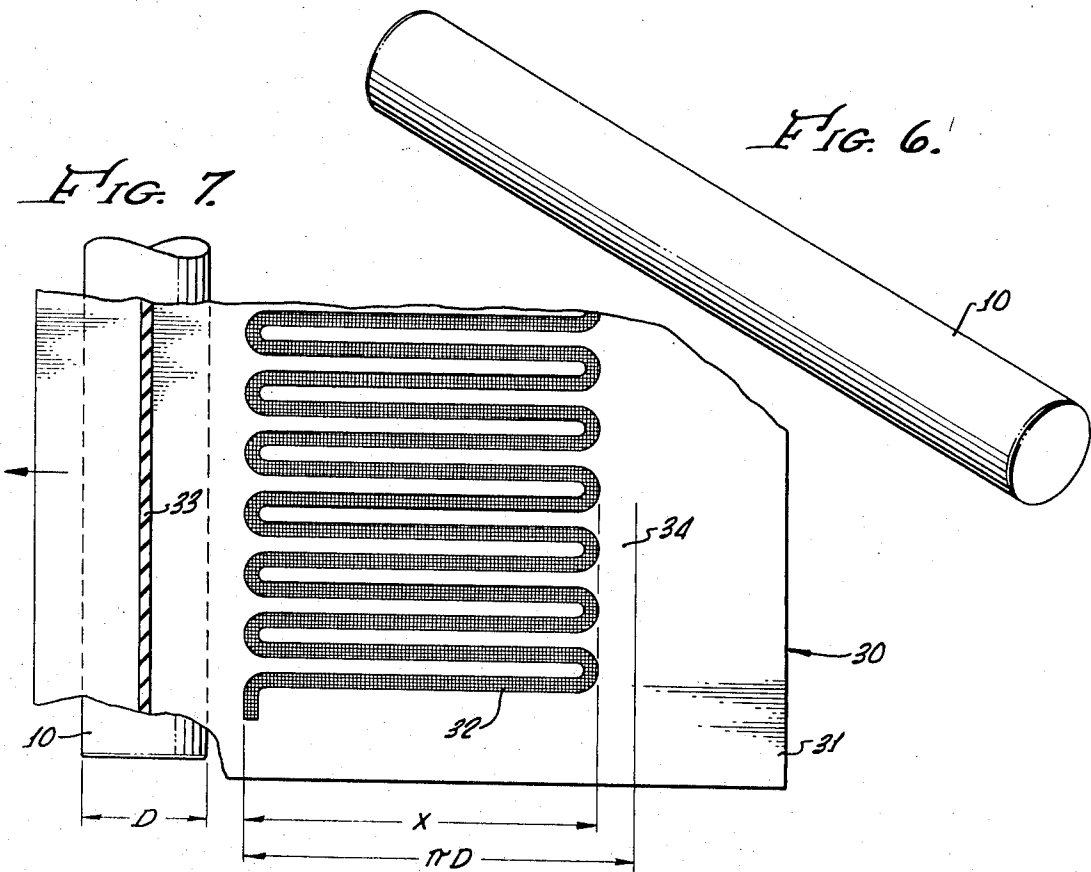
ABSTRACT

A film of electrically resistive material is provided on an elongated ceramic cylinder, in such a manner that there is a gap in the resistive material along the full length of one side of the cylinder and parallel to the cylinder axis. The gap is sufficiently wide that the squeegee of a silk-screening apparatus may be disposed therebetween at one point in the silk-screening process which is employed to manufacture the resistor. There is thus no necessity for overprinting at any time during silk-screening, the result being that no smudged or voltage-breakdown regions are created. The resistive film pattern is non-inductive, and comprises a serpentine wave formed of hairpinshaped portions which are disposed closely adjacent each other.

16 Claims, 10 Drawing Figures







NON-INDUCTIVE FILM-TYPE CYLINDRICAL RESISTOR

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of my co-pending application for "Non-Inductive Film-Type Cylindrical Resistor, and Method of Making the Same," Ser. No. 315,018, filed Dec. 14, 1972, now abandoned and the disclosure thereof is incorporated by this reference just as though it were fully set forth herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of film-type resistors wherein the film of resistive material is provided on the exterior surface of a cylinder. Throughout this specification and claims, the word "cylinder" is used in its conventional sense (a surface traced by a straight line moving parallel to a fixed straight axis and intersecting a fixed circle, the circle lying in a plane perpendicular to the axis, the circle having the axis as its center).

2. Description of Prior Art

Film-type resistors, wherein the resistive film is provided on the exterior surface of a cylinder, have long been known. For example, such a resistor is taught by Pat. No. 1,857,769, which describes the rotation of the cylinder while a helical film pattern is progressively drawn thereon. A similar process has been used by the company with which applicant is associated, except that a draftsman's (ruling, or bow) pen was used (instead of a wheel) to draw the helix on the rotating cylinder. Such operations were very slow and therefore expensive. Furthermore, the thickness of the film could not be controlled, or kept uniform, to the desired extent.

Another prior-art process for making cylindrical film-type resistors involved the coating of the cylindrical surface with resistive film, followed by the grinding of a narrow helical cut through such film. This was slow and expensive, and also involved additional disadvantages. For example, the grinding operation created a sharp and somewhat irregular edge along the film helix, which (particularly since the helical cut was narrow) increased the tendency toward voltage breakdown and shorting. Furthermore, the grinding operation tended to weaken the cylinder and make it more liable to break when subjected to physical or thermal shock.

All of the described helical patterns did not have noninductive characteristics, which characteristics are very desirable and important in numerous applications. For example, low inductance produces fast settling time (extremely short elapsed switching time before a steady-state condition is achieved).

There exist film-type cylindrical resistors wherein the helix is made left-hand along half of the cylinder length, and right-hand along the other, the purpose being to minimize inductance. However, such a pattern produces relatively efficient inductance compensation only in those turns near the center of the resistor. There are also, of course, numerous prior-art wire-wound (not film-type) cylindrical resistors which attempt to minimize inductance, but these are generally deficient relative to such factors as size, heat dissipation, cost, etc. Furthermore, they frequently do not reduce induc-

tance to the same extent as do the resistors described and claimed herein.

Low inductance film-type resistors are known wherein the underlying surface (substrate) is flat instead of cylindrical. For example, the company with which applicant is associated manufactures such resistors by silk-screening methods. However, flat surfaces are impractical and/or undesirable in numerous applications. For example, where the flat substrate is thin, it has poor resistance to thermal and physical shock. Thermal shock is an especially major consideration, since the resistor may be very rapidly heated to several hundred degrees Fahrenheit. Where the substrate is thick, it tends to have a relatively irregular surface which is difficult to coat with the desired pattern of resistive material. Cylindrical substrates, on the other hand, have (particularly when they are solid instead of hollow, and are not scored) high shock resistance. They also have very smooth and regular surfaces, which are economically formed by centerless grinding. Cylindrical resistors also have other important advantages, such as the ability to be very small while generating high resistances.

Silk-screening of a pattern onto a cylindrical substrate can be accomplished in a matter of seconds instead of minutes. However, it has long been thought that silk-screening is impractical in the field of film-type cylindrical resistors. It is believed that the thinking of prior-art workers was largely locked to the traditional helical film pattern, and a helix may not be silk-screened without overprinting part of the pattern. Overprinting is often fatal to the integrity of the resistor, since it produces disuniform film thicknesses as well as tending toward smudging and thus short-circuiting of turns of the helix. It is emphasized that (a) overprinting is especially intolerable where the elongated strip of film (forming the pattern) is narrow, and (b) narrow strips are often highly desirable, for example to increase resistance.

SUMMARY OF THE INVENTION

The present film-type resistor may be produced by using silk-screen processes, which require only seconds to perform, the result being that high quality resistive elements may be manufactured with relative economy. Furthermore, the resistors are highly non-inductive, are very resistant to thermal and physical shock, and have great immunity to voltage breakdown and shorting. The resistors may be small in size, yet are capable of having multi-megohm resistance values. The film strip forming the pattern can be very narrow, such as 0.010 inch, which permits accurate manufacture of such high-resistance resistors.

In the present resistor, the resistive film is present on large areas of the exterior cylindrical surface of a substrate, but is not present at a substantial gap which extends along one side of the cylindrical surface and parallel to the axis. Such gap is sufficiently wide to prevent voltage breakdown between resistive film portions on opposite sides thereof, and is also sufficiently wide to permit the silk-screen squeegee to be disposed at the gap without causing any overprinting of the film pattern. The film portions immediately adjacent the gap are preferably the apex (bend or turn) portions of the serpentine wave pattern formed by the film.

Stated more specifically, the serpentine wave pattern is composed of a multiplicity of hairpin-shaped por-

tions each having an apex at the end thereof, the arms of each portion being parallel and adjacent each other. Thus, current flows in opposite directions through adjacent arms to effect efficient cancellation of the generated magnetic fields, with consequent substantial absence of inductance. The spaces between adjacent arms preferably have about the same widths as do the arms themselves, the result being that the tendency toward voltage breakdown is minimized.

In accordance with the method, the silk screen is moved in only one direction during the printing stroke, and is stopped when the squeegee is located at the gap. There is thus no overprinting, and no tendency for the resulting pattern to be susceptible to short circuits. The resistor is separated from the screen before the latter returns to its original position.

In summary, therefore, applicant has created an economically mass-producible film-type cylindrical resistor, having sufficient quality to satisfy the most exacting specifications, and having improved non-inductive and other characteristics in relation to prior-art film-type resistors. The resistor has an accurately-determined resistance value, which may be very high despite the fact that the resistor is small. This achievement has resulted largely from use of a film pattern which may be applied by silk-screening, with no overprinting.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a greatly enlarged isometric view showing a film-type resistor embodying the present invention, but prior to the depositing of an external coating thereon;

FIG. 2 is a side elevational view of the resistor as shown in FIG. 1, but showing the reverse side from that shown in FIG. 1;

FIG. 3 is a longitudinal central sectional view of the resistor, with the external coating thereon;

FIG. 4 is a further enlarged fragmentary sectional view corresponding to a small region of the lower portion of FIG. 3, but with no external coating;

FIG. 5 is an enlarged cross-sectional view taken on line 5—5 of FIG. 3;

FIG. 6 is an isometric view showing the cylindrical substrate on which the resistive film is printed;

FIG. 7 is a top plan view showing schematically a silk-screen apparatus employed to manufacture the present resistor;

FIG. 8 is a plan view showing the resistor after the resistive film pattern has been printed thereon, and after terminal films have been printed at the ends of the cylinder;

FIG. 9 is an isometric view illustrating one manner of accurately adjusting the resistance value of the resistor; and

FIG. 10 is a side elevational view of the completed resistor having the protective coating thereon.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIGS. 1 and 2, the resistor comprises an elongated cylinder 10 (the substrate) formed of electrically insulating material, preferably a suitable heat-resistant ceramic such as aluminum oxide. To increase the strength thereof, and to minimize the possibility of moisture introduction, cylinder 10 is preferably solid as distinguished from hollow. It has a smooth

exterior surface which is formed by centerless grinding a ceramic extrusion.

Provided exteriorly on cylinder 10, in adherent relationship relative to the cylindrical surface, is a resistive film 11. The film comprises an elongated strip 12 which is shaped in a certain pattern adapted to provide the requisite characteristics of noninductance, prevention of voltage breakdown, etc.

Although the resistive film 11 is present at major areas on the surface of cylinder 10, it is not present along a gap 13 which extends for the full length of cylinder 10 and parallel to the axis thereof. Gap 13 is sufficiently wide that there will not be any voltage breakdown between portions of film 11 on opposite sides of the gap, and is also sufficiently wide that the squeegee of a silk-screening apparatus (described below) may be disposed in the gap without resulting in any overprinting of the resistive film pattern. Gap 13 is at least about 0.015 inch wide.

The pattern of film 11 may be described as serpentine or sinuous, and is non-inductive in nature. The pattern comprises a multiplicity of series-related hairpin-shaped portions each having a U-shaped base (turn or bend) 14 and also having parallel arms 16. Adjacent arms 16 pass current in opposite directions, the result being that the generated magnetic fields efficiently neutralize each other to prevent the creation of substantial inductance in the resistor.

The width of strip 12, that is to say the width of each arm 16 and each base 14, is small. The range may be between about 8 thousandths of an inch and about 100 thousandths of an inch. It is possible to have widths of arms 16 less than 8 thousandths, but it may interfere with production speed and repeatability.

In the illustrated embodiment, the serpentine wave forming the resistive film pattern is wrapped around the cylindrical surface of cylinder 10, in such manner that the U-shaped bases are disposed adjacent each other on opposite sides of gap 13. Stated otherwise, there are two parallel rows of bases 14, one row on each side of gap 13. The arms thus extend circumferentially of the cylindrical surface, whereas at least portions of the bases extend longitudinally thereof.

With the described construction, each arm 16 is relatively short, being substantially less than the circumference of cylinder 10. Because of the short lengths of the arms 16 in the illustrated embodiment, the voltage drop along any arm is insufficiently great to create a large voltage differential relative to the adjacent arm, so that the tendency toward voltage breakdown is minimized.

In the illustrated embodiment, and in many preferred embodiments, the width of each arm 16 is substantially the same as the width of each space between adjacent arms, except that the width of each space is preferably about 50 thousandths of an inch or less for highly effective inductance cancellation. Such spaces are illustrated, for example, at 17 in FIGS. 1-4. The widths of spaces 17 may range from about 8 thousandths of an inch to a maximum of about 100 thousandths of an inch, preferably much closer to 8 thousandths in order to minimize inductance.

To achieve effective inductance cancellation action, each space 17 between adjacent arms 16 of the strip 12 has a maximum width of 100 thousandths of an inch although a width of 50 thousandths of an inch or less is preferred. A width of space 17 greater than 100 thou-

sandths of an inch affords little useful cancellation of inductance between adjacent arms. It will be understood that inductance cancellation is enhanced as the width of each space 17 is made smaller, such as down to about 8 thousandths of an inch. It is possible to have widths of space 17 less than 8 thousandths of an inch, but this may interfere with production speed and repeatability. Accordingly, in one desirable embodiment the width of each of arms 16 and the width of each space 17 is about 8 thousandths of an inch.

The thickness of strip 12 (as distinguished from the width thereof) is preferably between about one-half a thousandth of an inch at its maximum dimension and about 2 thousandths of an inch at its maximum dimension. Referring to FIG. 4, it is pointed out that the exterior surfaces of the edge portions of strip 12 taper (converge) toward the cylindrical surface, so that there is no sharp corner or dropoff point. This "feathered" shape tends to minimize the possibility of voltage breakdown.

In the illustrated embodiment, one portion of the resistive film pattern is relatively wide, as shown at 18. This permits the resistor to be trimmed or adjusted, relative to its resistance value, as described below. An abraded (and thus thinned, or cut away) region 19 (FIG. 1) is provided in the wide portion 18, the length and width of the abraded region being such as to cause the resistive film to have a resistance value in a desired narrow range.

At opposite ends of the serpentine strip 12 of resistive film are terminal portions 21 which preferably extend parallel to the axis of the cylinder 10 and adjacent (but not in) gap 13. The terminal portions 21 extend beneath cylindrical films 23 and 24 (FIGS. 3, 5 and 8) of highly conductive material, which films are formed on cylinder 10 at opposite ends thereof. Films 23 and 24 create great uniformity in the termination resistance, and minimize contact-resistance problems.

The films 23 and 24 may be formed of a silver-ceramic conductive material in a glass matrix, or they may be formed of a silver-epoxy conductive plastic.

The resistive material forming film 11 may comprise electrically conductive complex metal oxides in a glass matrix, and which are fired in air (for example, for thirty minutes) at temperatures above 1400° F. To permit the complex oxides and glass particles to be silk-screened, they are first mixed with a pin oil (squeegee oil) vehicle. Another resistive material which may be employed is carbon particles, in an epoxy vehicle which also acts as an adhesive or binder.

Although the illustrated wrap-around serpentine film pattern is greatly preferred, it is possible to provide other film patterns wherein the gap 13 is present and wherein substantially non-inductive relationships result. For example, the arms of the serpentine wave may extend parallel to the axis of cylinder 10 as distinguished from being circumferential. The U-shaped bases then extend circumferentially, as distinguished from the present bases which extend (at least at their midportions) generally parallel to the cylinder axis.

The present resistors frequently become very hot, for example being heated to several hundred degrees F. For this reason, it is normally impractical to employ solder to form the end terminals of the resistor. Therefore, metal end caps or cups 26 are press-fit over the ends of cylinder 10, that is to say over the cylindrical films 23 and 24, and form contact with such films 23

and 24 and thus with terminal portions 21. Axial leads 27 extend outwardly from the end caps 26, being electrically and physically connected to such end caps by suitable means.

The resistor further comprises an environmentally protective coating 28 (encapsulating means) formed of a suitable material having the requisite characteristics relative to insulating ability, moisture resistance, heat resistance, etc. A preferred coating material is silicone conformal, which may be purchased from Midland Industrial Finishes Company, of Waukegan, Illinois.

For extremely high voltage applications, there may be both primary and secondary encapsulation of the resistive film. There may also be shielding therearound, for example silver shielding grounded to one lead.

DESCRIPTION OF THE METHOD

Referring next to FIGS. 6-10, the method comprises providing an elongated cylinder 10 formed of a desired substrate such as aluminum oxide ceramic. As indicated above, the exterior cylindrical surface of the cylinder 10 is caused to be smooth and very round, preferably by centerless grinding techniques. The illustrated cylinder has a diameter D as shown at the left in FIG. 7.

As the next step in the method, the resistive film 11 is printed on the exterior surface of cylinder 10 at major regions thereof, but not at the gap 13. Such printing is effected rapidly, and is to be distinguished from the progressive "drawing" of the pattern on the surface as was done, for example, by the apparatus disclosed in the above-cited Pat. No. 1,857,769.

The printing is effected by causing rolling contact to occur between a printing member 30 and the cylindrical surface of cylinder 10. The member 30 has a printing area provided thereon and which is related to the diameter of cylinder 10 as described below. The rolling contact which takes place between cylinder 10 and printing member 30 is straight-line contact, being along a line parallel to the axis of cylinder 10. There is no sliding contact between the member 30 and the cylinder, and there is no overprinting of material printed on the cylinder.

Stated more specifically, the printing member 30 is of the stencil type, being a "silk screen" having an impervious portion 31 and a pervious portion 32. The shape, dimensions, etc., of pervious portion 32 correspond to those of the resistive film pattern described above except that, in the illustrated apparatus, the pervious portion 32 is planar. The dimension of the printing area (pervious portion 32) in the direction of screen movement is X, and is equal to π times D minus the width of gap 13 described above.

The silk-screen apparatus further comprises a squeegee 33 which is supported by suitable means, not shown. The squeegee engages the upper surface of silk screen 30 above the upper region of cylinder 10, the region of the screen engaged by the squeegee being in straight-line contact with the cylinder along a line parallel to the cylinder axis. Suitable means, not shown, are provided to rotatably support the extreme ends of cylinder 10 in such manner that the cylinder will rotate with the screen as the latter is moved beneath the squeegee 33, or to drive the cylinder 10 to effect rotation thereof at a speed corresponding to the speed of movement of the screen.

In performing the silk-screening operation, a suitable wiper member (not shown) is provided to wipe across the upper surface of screen 30 and impregnate all of the pervious portion 32 with resistive material, for example with the complex oxide resistive material indicated above. Thereafter, screen 30 is moved to the left (as viewed in FIG. 7) beneath squeegee 33, the amount of movement being such that each portion of the printing area of the silk screen 30 (namely, the pervious portion 32 of the silk screen) engages cylinder 10 once and only once.

Thus, where the printing area (pervious portion 32) of silk screen 30 has a dimension X in the direction of movement of screen 30, the amount of screen movement which is caused to occur after the most advanced (forward) portion of the printing area engages squeegee 33 is greater than X but less than π times D. Accordingly, at the completion of the leftward printing stroke of screen 30, the screen region indicated at 34 in FIG. 7 is beneath squeegee 33. Such region 34 corresponds to the gap 13, as shown in FIG. 8, which gap has a width equal to π times D minus X.

After completion of the printing stroke, the printed cylinder 10 is removed so that it no longer contacts screen 30. Thereafter, screen 30 is moved in the reverse direction (to the right as viewed in FIG. 7) and, at the same time, the wiper means causes wiping of a new amount of resistive material into the pervious portion 32 of the screen. Thus, the apparatus is ready for the next printing stroke.

The printed cylinder 10 is then fired in air, in a furnace, at temperatures in excess of 1400° F., in order to effect melting of the glass and curing of the resistive material. Such firing is continued for 30 minutes.

Thereafter, the cylindrical films 23 and 24 of highly conductive termination material (such as the silver-ceramic material indicated above) are provided at opposite ends of the cylinder and over the terminal portions 21 of the resistive film. The cylinders are then again fired, for (for example) 5 minutes at 1100° F.

As the next step in the method, the end caps 26 are press fit over the films 23 and 24, and the associated leads 27 are electrically connected to leads 35 shown in FIG. 9 and which are part of a resistance testing device. The device further comprises an ohmmeter 36 and a power source 37. When power is applied from source 37, the meter 36 indicates the resistance of the resistive film pattern in the resistor being tested.

In production, the as-formed resistive film is caused to have a resistance slightly less than the desired final resistance. Therefore, the resistance is increased until the meter 36 reads the desired value. Such increase may be effected in different ways, the illustrated one being to direct from nozzle 38 (FIG. 9) a high-velocity blast of abrasive material, the blast being localized in the wide portion 18 of the pattern. The result of the blast is to abrade away the resistive material and therefore increase the length of the path through which the current must flow in passing between the ends of the cylinder. As the current path length is thus increased, the resistance of the resistive element increases until the meter 36 reads the desired value.

Another method of thus adjusting the resistance is to abrade away, as by a grinding operation, the entire exterior of the resistive film 11, the amount of such grinding being only very little but being sufficient to cause the film to be somewhat thinner than before. The de-

gree of thinning is made sufficient to raise the resistance until the meter 36 reads as desired.

As the final step in the method, the environmentally protective coating 28 is provided, as by spraying or dipping, to result in the finished product shown in elevation in FIG. 10.

ALTERNATIVE CONSTRUCTIONS AND METHODS

An alternative but generally much less desirable method of manufacturing resistors, using the silk-screen printing process, is to coat the entire exterior surface of cylinder 10 with resistive material. For example, there is vapor-deposited on the cylinder a coating of resistive metal such as a nickel-chromium alloy. Thereafter, the silk-screening process described above relative to FIG. 7 is employed to silk screen onto the vapor deposited metal a pattern of acid-resist material. Thus, the silk-screen process is the same except that the material printed onto the substrate is acid-resist material instead of electrically-resistive material.

As the next step in the method, an acid-etching step is employed to etch away all of the vapor-deposited metal excepting that which is protected by the acid resist. Thereafter, the acid-resist material is dissolved off of the metal which was thus protected, so that the only thing remaining on the surface of the substrate 10 is a pattern of vapor-deposited metal corresponding, for example, to the pattern shown and described in FIGS. 1 and 2. Thereafter, termination films are provided, end caps are mounted, and the environmentally-protective encapsulating layer is applied.

The word "resistive", as employed in this specification and claims, denotes a film which (a) is not an electrical insulator, (b) is an electrical conductor, (c) is not a good electrical conductor, and (d) has a substantial amount of electrical resistance.

The foregoing detailed description is to be clearly understood as given by way of illustration and example only, the spirit and scope of this invention being limited solely by the appended claims.

I claim:

1. A film-type electrical resistor, which comprises:
 - a. an elongated cylindrical heat-resistant substrate,
 - b. an electrically resistive film adherently provided by the silk-screen process on the exterior cylindrical surface of said substrate, said resistive film comprising an elongated narrow strip of resistive material, said strip having such a cross-sectional shape, in a direction perpendicular to the length of said strip, that the exterior surfaces of the edges of said strip converge toward said cylindrical surface in a feathered manner, said film being present on substantial portions of said surface, but being absent at a gap which extends along the full length of one side of said surface parallel to the axis of said substrate, and
 - c. termination means electrically connected to opposite end portions of said resistive film, and permitting connection of said film in an electrical circuit.

2. The invention as claimed in claim 1, in which the width of said gap is at least 15 thousandths of an inch.

3. The invention as claimed in claim 1, in which said strip is shaped in a serpentine manner, whereby current

flows in opposite directions through adjacent portions of said strip, thereby minimizing the inductance of the resistor.

4. The invention as claimed in claim 3, in which said serpentine strip comprises a multiplicity of hairpin-shaped portions the arms of which are substantially parallel to each other, said arms being connected to each other by base portions, and in which each of said arms is spaced less than 100 thousandths of an inch from each adjacent arm to thereby achieve effective cancellation of the inductance of the resistor.

5. The invention as claimed in claim 4, in which the width of said strip is substantially equal to the widths of the spaces between adjacent arms of said hairpin-shaped portions.

6. The invention as claimed in claim 4, in which the width of said strip is in the range of about 8 thousandths of an inch to about 100 thousandths of an inch, and in which the widths of the spaces between adjacent arms of said hairpin-shaped portions is in the range of about 8 thousandths of an inch to about 50 thousandths of an inch.

7. The invention as claimed in claim 4, in which said arms of said hairpin-shaped portions extend circumferentially of said cylindrical surface, and in which said base portions extend generally longitudinally of said cylindrical surface, one row of said base portions being on one side of said gap, the other row of said base portions being on the opposite side of said gap, said rows extending parallel to the substrate axis along circumferentially-offset longitudinal side portions of said surface.

8. The invention as claimed in claim 1, in which said cylindrical substrate is a solid ceramic cylinder, and is not hollow.

9. The invention as claimed in claim 1, in which said termination means comprises highly conductive films adherently provided at opposite ends of said cylindrical surface and in electrical contact with opposite end portions of said resistive film, and further comprises conductive end caps press fit over said conductive films and connected to leads which extend outwardly from the resistor.

10. The invention as claimed in claim 1, in which the maximum thickness of said film is in the range of about 0.0005 inch to about 0.002 inch.

11. A low-inductance film-type resistor, which comprises:

- a. an elongated cylindrical substrate formed of a heat-resistant ceramic, said ceramic being solid, not hollow, for the full length thereof, the cylindrical surface of said substrate being smooth and ungrooved,

- b. a resistive film adherently provided by the silk-

screen process directly onto the exterior cylindrical surface of said substrate,

the thickness of said film being between about 0.0005 inch and about 0.002 inch, the exterior surfaces of the edges of said film tapering in feathered manner toward the exterior cylindrical surface of said substrate,

said film being present on major portions of said surface, but being absent at all portions of a gap which extends along the full length of one side of said surface parallel to the axis of said substrate,

the width of said gap being at least 15 thousandths of an inch,

said film comprising an elongated narrow strip of resistive material,

said strip being shaped in a serpentine manner and being formed of a multiplicity of parallel arms connected by base portions,

each of said parallel arms being spaced less than 100 thousandths of an inch from each adjacent arm,

c. termination films formed of conductive material and adherently provided on said cylindrical surface at opposite ends thereof,

said films being respectively connected to opposite end portions of said serpentine strip,

d. end caps press fit over said conductive films and being connected to leads, and

e. means to encapsulate said film-coated substrate to environmentally protect the same.

12. The invention as claimed in claim 11, in which said arms extend circumferentially of said cylindrical surface and said base portions extend generally longitudinally thereof, and in which said base portions are disposed on opposite sides of said gap.

13. The invention as claimed in claim 11, in which the width of said strip is substantially equal to the spacing between adjacent arms.

14. The invention as claimed in claim 11, in which the width of said strip is in the range of about 0.008 inch to about 0.100 inch, in which the width of each of the spaces between adjacent arms is in the the range of about 0.008 inch to about 0.050 inch.

15. The invention as claimed in claim 1, in which said termination means comprises conductive end caps mounted over opposite ends of said substrate.

16. The invention as claimed in claim 11, in which said film is in the form of an elongated narrow serpentine strip each arm of which is parallel to and less than 100 thousandths of an inch distant from each adjacent arm, whereby current flows in opposite directions through adjacent arms and because of the arm proximity creates an effective inductance-cancellation action.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,858,147 Dated December 31, 1974

Inventor(s) Caddock, Richard E.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 47, "pin", should be "pine".

Signed and sealed this 8th day of April 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,858,147 Dated December 31, 1974

Inventor(s) Caddock, Richard E.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 47, "pin", should be "pine".

Signed and sealed this 8th day of April 1975.

(SEAL)

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

REEXAMINATION CERTIFICATE (1172nd)

United States Patent [19] [11] **B1 3,858,147**

Caddock [45] Certificate Issued **Dec. 19, 1989**

**[54] NON-INDUCTIVE FILM-TYPE
CYLINDRICAL RESISTOR**

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Reexamination Request:

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Reexamination Certificate for:

Patent No.: **3,858,147**
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Filed: **Dec. 14, 1973**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 315,018, Dec. 14, 1972, abandoned.

[51] Int. Cl.⁴ H01C 3/02
[52] U.S. Cl. 338/62; 338/63;
338/286; 338/292; 338/300; 338/302; 338/262;
338/332
[58] Field of Search 338/61-63,
338/262, 286, 294, 292, 300, 302, 308, 332

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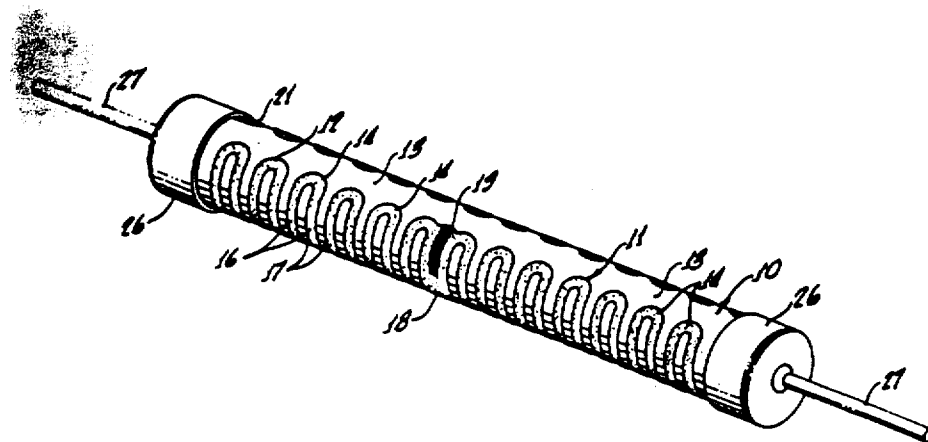
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Primary Examiner—Leo P. Picard

[57] ABSTRACT

A film of electrically resistive material is provided on an elongated ceramic cylinder, in such a manner that there is a gap in the resistive material along the full length of one side of the cylinder and parallel to the cylinder axis. The gap is sufficiently wide that the squeegee of a silk-screening apparatus may be disposed therebetween at one point in the silk-screening process which is employed to manufacture the resistor. There is thus no necessity for overprinting at any time during silk-screening, the result being that no smudged or voltage-breakdown regions are created. The resistive film pattern is non-inductive, and comprises a serpentine wave formed of hairpinshaped portions which are disposed closely adjacent each other.



REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS
INDICATED BELOW.

Matter enclosed in heavy brackets **[]** appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS
BEEN DETERMINED THAT:

The patentability of claims 11-14 and 16 is confirmed.

Claims 1-3, 8-10 and 15 are cancelled.

Claim 4 is determined to be patentable as amended.

Claims 5-7, dependent on an amended claim, are determined to be patentable.

New claims 17-20 are added and determined to be patentable.

4. **[The invention as claimed in claim 3, in which] A** film-type electrical resistor, which comprises:

- a. an elongated cylindrical heat-resistant substrate,
- b. an electrically resistive film adherently provided by the silk-screen process on the exterior cylindrical surface of said substrate, said resistive film comprising an elongated narrow strip of resistive material, said strip being shaped in a serpentine manner, whereby current flows in opposite directions through

adjacent portions of said strip, thereby minimizing the inductance of the resistor,

said serpentine strip **[comprises]** comprising a multiplicity of hairpin shaped portions the arms of which are substantially parallel to each other, said arms being connected to each other by base portions, **[and in which]** each of said arms **[is]** being spaced less than 100 thousandths of an inch from each adjacent arm to thereby achieve effective cancellation of the inductance of the resistor,

said strip having a cross-sectional shape, in a direction perpendicular to the length of said strip, that the exterior surfaces of the edges of said strip converge toward said cylindrical surface in a feathered manner, said film being present on substantial portions of said surface, but being absent at a gap which extends along the full length of one side of said surface parallel to the axis of said substrate, and

c. termination means electrically connected to opposite end portions of said resistive film, and permitting connection of said film in an electrical circuit.

17. The invention as claimed in claim 4, in which said cylindrical substrate is a solid ceramic cylinder and is not hollow.

18. The invention as claimed in claim 4, in which said termination means comprises highly conductive films adherently provided at opposite ends of said cylindrical surface and in electrical contact with opposite end portions of said resistive film, and further comprises conductive end caps press fit over said conductive films and connected to leads which extend outwardly from the resistor.

19. The invention as claimed in claim 4, in which the maximum thickness of said film is in the range of about 0.0005 inch to about 0.002 inch.

20. The invention as claimed in claim 4, in which said termination means comprises conductive end caps mounted over opposite ends of said substrate.

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